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ENGRAVING OF ROTATING BANDS – A MODIFICATION OF METAL-FLOW PATTERN

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JUNE 1983

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An evaluation of the commencement-of-rifling (C.O.R.) geometry suggests that the mode of deformation of the rotating band by the rifling is inefficient. Observation of rotating bands of fired and retrieved projectiles confirms the above evaluation. Engravers, simulating the conventional design of C.O.R. as well as the proposed modification, were fabricated. Slugs of rotating band material were engraved with the simulated engravers. Metallographic data on
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20. ABSTRACT (CONT'D)

the laboratory engraved slugs were compared with those of retrieved projectiles; results from the two simulating designs were also compared. Similarities were found between retrieved bands and simulated conventional design, while the simulated modification resulted in change in metal-flow pattern close to the intended one. Reduced engraving forces were observed as predicted and can be explained by reduced deformation forces when the modified design of C.O.R. is being simulated. It is suggested that reduced deformation forces will reduce wear at the commencement-of-rifling.

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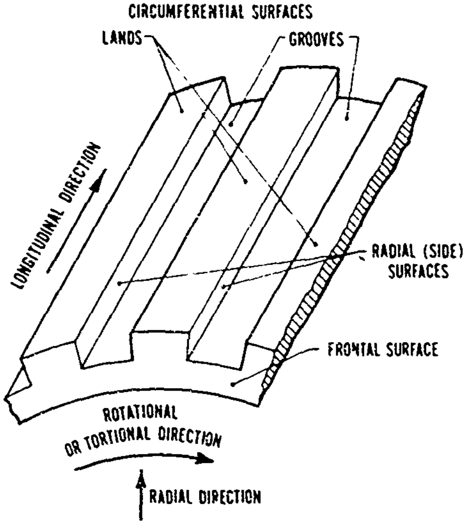
I would like to express my appreciation for the help I received from Mrs. Theresa Brassard and Mr. Christopher Lickard in the preparation of macrographs and micrographs. I would also like to acknowledge Mr. Richard Warenchak and Mr. Leo Szymanski for help in simulating the engravings, Dr. Fritz Sautter for his moral support and encouragement in undertaking this assignment, and Dr. Paul Cote for coediting the manuscript.

INTRODUCTION

Engraving is a process by which a rotating band, on a spin-stabilized projectile, assumes a complimentary form with the firing tube's rifling. As the name implies, its primary purpose is to impart a rotational motion to the projectile. In addition, by filling the grooves in the tube's rifling, the rotating band slows down leakage of propellant gases past the projectile. Ideally it should stop such leakage completely.

Design dimensions of the grooves in the tube and of the O.D. (outer diameter) of the rotating band call for interference; the O.D. of the rotating band is made larger than the rifling grooves' diameter. For an 8-inch gun tube the grooves' diameter is $8.140^{+.006}_{-.000}$, while the O.D. of the rotating band on a corresponding projectile is $8.195^{+.000}_{-.005}$, or an interference of .044 inch to .055 inch in diameter (which is .54 percent to .67 percent of the diameter, and it is to be compared with grooves' depth of .070 inch on each side). If such an interference prevails during firing, the excess material (.044 inch to .055 inch) will be shaven at the rifling grooves and in between it will be pushed backward by the rifling lands. To accommodate for the backward metal-flow, the rotating bands are provided with periodic circumferential channels called cannelures. This investigator is convinced that the longitudinal push along the circumferential surfaces and the shear along the radial (side) surfaces of the rifling lands (see Figure 1) at the commencement-of-rifling (C.O.R.), are too severe. The energy required to engrave the band in this fashion is high and the wear on the tube's rifling is severe. Hence, I suggest a modification of the flow pattern in the rotating band material during engraving through a change in the design of the

commencement-of-rifling. This change is intended to maintain the configuration of the rifling beyond its commencement. The concept involved can accommodate any change in the rifling configuration and/or surface treatment and thus be complimentary to such a change rather than a substitute for it.



A SEGMENT OF AN ENGRAVED ROTATING BAND

Figure 1.

OBSERVATIONS

Visual and microscopic evaluation of the rotating bands of fired and retrieved projectiles revealed the following:

a. As seen in Figure 2, material removed by the rifling land has been pushed backward by the lands. In some locations, the rotating band material between the rifling lands failed to fill the rifling grooves. This is evidenced by the retention of machining marks on the rotating band. During firing, the tube below the projectile is subjected to the propellant's pressure and thus to radial expansion. Under the same pressure, the projectile's tail end may contract radially. These forces may be augmented by the radial component of the engraving forces. However, as mentioned above for the 8-inch tube and projectile, the interference between the as-machined gun tube and the as-machined rotating band is between .54 percent to .67 percent of their nominal diameter. It is beyond the scope of this investigation to accurately determine the factors that contribute to the band's failure to completely fill the rifling grooves. Nevertheless, this observation will be referred to in the discussion of the simulated engraving (namely, simulating both designs - the prevailing one as well as the suggested modification).

Figure 2 A Segment of an Engraved Rotating Band [illegible]
S" Projectile

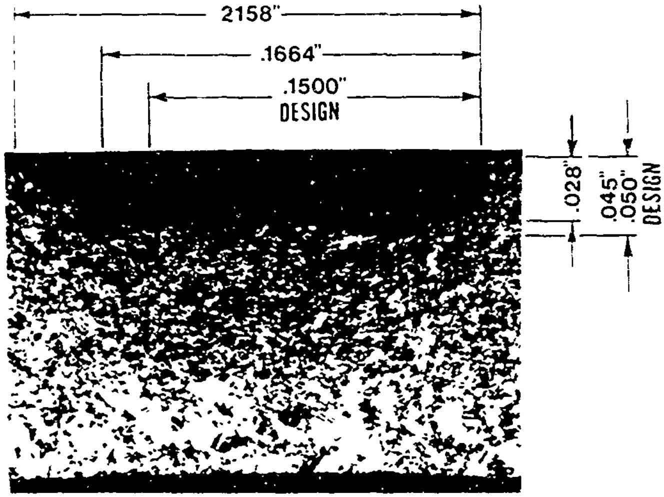


Figure 3a   Engraved Rotating Band on a 105 mm Projectile - Transverse Section.

b. The above micrograph (Figure 3a) reveals a total groove depth of about .028 inch in the rotating band, while the rifling land's height is designed to be .030 inch to .032 inch. This reemphasizes point "a" above, suggesting an incomplete filling of the rifling grooves by rotating band material. Moreover, according to Figure 3a, the width of the engraved groove is .1664 inch to .2158 inch, whereas the designed width of the rifling land is only .1500 inch. Since this retrieved projectile was fired from a howitzer with degressive twist (of its rifling), the widening of the groove on the rotating band can be attributed partially to the change in twist angle and partially to torsional wear. The slope of one side of the band's groove can be attributed to progressive torsional wear at the early stages of engraving (at the commencement-of-rifling). Usually, however, torsional wear develops gradually throughout the length of the tube. Whatever the mechanism is, the widening of the grooves allows for gas leakage to the front of the projectile.

c. The microstructure of a transverse cut through the rotating band's groove (Figure 3b) reveals that in a retrieved rotating band of a 105 mm projectile, up to about .008 inch below the surface has been heavily deformed and recrystallized. Also, a layer of up to .055 inch to .075 inch (total) has been deformed to a noticeable degree.

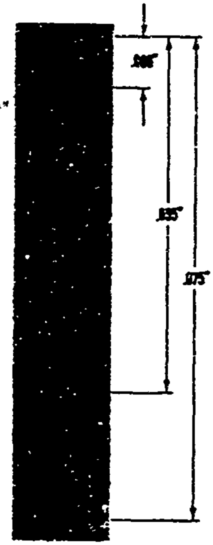


Figure 3b. Transverse Cut Through an Engraved Groove of a Rotating Band of a 105 mm Projectile - Reduced 50 Percent from 100X Magnification.

Figure 3c. Transverse Cut Through the Land of an Engraved Rotating Band of a 105 mm Projectile - Reduced to 75 Percent of 100X Magnification.

d. Cross section of a rotating band from a retrieved 8-inch projectile (Figure 4) shows engraving depth of .057 inch to .066 inch or about 81 percent to 94 percent of the design height of the rifling land. However, the width of the engraved groove is .2193 inch, whereas the designed width of the engraving land is only .1571 inch or about 40 percent larger than it was designed to be. If these numbers are representative ones (the verification of which is beyond the scope of this investigation), then one conclusion is that despite the almost complete filling of the rifling grooves, gas leakage is still a possibility.

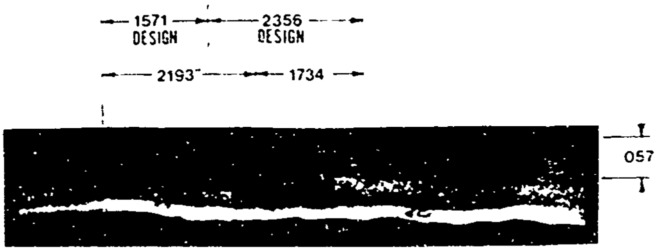


Figure 4. A Transverse Cut Through a Rotating Band of an 8" Projectile - Reduced to 75 Percent of a 75X Magnification.

In summary, the above numbers suggest that the wear in the rotating band of the 105 mm projectile fired through a howitzer, was between 4.5 percent and 18 percent of its circumference, while on the retrieved 8-inch projectile it was about 15.8 percent. It is anticipated that these values will vary with the firing zone for the same projectile size and weight.

BACKGROUND

Most available studies where gross plastic deformation is involved address themselves to continuous processes such as wire drawing or rolling.[1,2] In these processes one can divide the material into three zones:

a. Rigid incoming material.

b. Deformation zone.

c. Rigid outcoming product.

Except at the start and end of the process, the size and shape of the deformation zone is independent of time and so is the stress and/or strain rate distribution throughout the deformation zone. The two leading methods of approximating these stress and strain rate fields are:

a. Limit analysis, which is discussed intensively by Avitzur.[1]

b. The slip line field method, which is discussed by Thomsen et al.[2]

The problem at hand, however, deals with a deformation where the shape of all three zones, the incoming material, the deformation zone, and the final product, varies as the process progresses.

The above mentioned literature,[1,2] as well as other literature, treats such processes as simple forging of a disc or deep drawing of sheet metal into a cup. However, as the process deviates from one of rotational symmetry, it becomes more tedious to analyze the stress and/or strain rates at each instant of the process while in progress. Such studies can be aided experimentally by spliting the samples and imbedding grid lines which will be evaluated as the

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[1]Avitzur, B., Metal Forming: Processes and Analysis, McGraw-Hill, 1968.
[2]Thomsen, E. G., Yang, C. T., and Kobayashi, S., Mechanics of Plastic Deformation in Metal Processing, The MacMillan Co., NY, 1965.

process progresses.[2] This procedure is tedious and costly and was not used in this study. An intensive search for such studies by past investigators can be summarized as follows: "The engraving process was not analyzed," so far, "due to lack of adequate data for loading input and the reliability of results in an elastic-plastic modeling problem."[3]

In view of the above background, this investigation bypassed any analytical evaluation of either the prevailing design of commencement-of-rifling, or the suggested modification of the latter. This study was guided by the principle that reducing redundant work (of engraving) should reduce the required energies and engraving forces. Professor Backhoffen's definition of redundant work, as

$$D = \frac{L}{H}$$

where H equals depth of deformation zone and L equals width of deformation zone, was one of the criteria used in modifying the design of the commencement-of-rifling.

LABORATORY SIMULATION

The simulator consists of a steel block, an engraving plate, and a moving cage that contains a slug to simulate the rotating band (Figure 5). The first tested engraving plate simulated the rifling and its commencement in an 8-inch tube. In order to simplify the process and to reduce complications by factors

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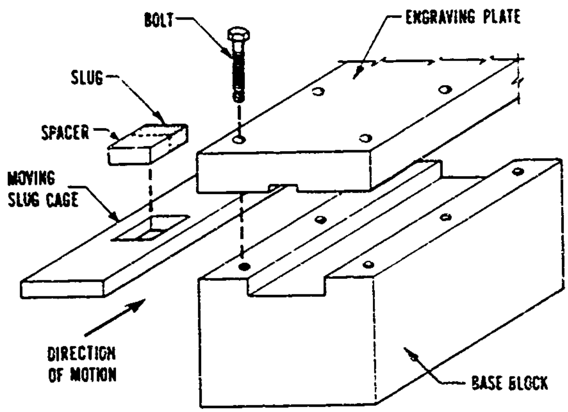
[2]Thomsen, E. G., Yang, C. T., and Kobayashi, S., Mechanics of Plastic Deformation in Metal Processing, The MacMillan Co., NY, 1965.

[3]Rottenberg, M. M. and Bowers, J. M., "Rotating Band for High Velocity Thin Walled 30 mm Projectiles," Air Force Armament Laboratory Technical Report, AFATL-TR-79-73, August 1979.

of secondary importance, lateral movement of the slug was eliminated. Therefore, a straight rifling was used instead of the rotational twist in actual gun tubes.



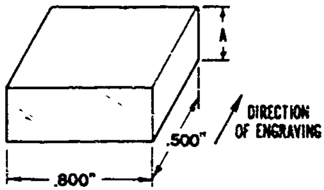
ENGRAVING SIMULATION APPARATUS

Figure 5.

While the total width of a rotating band on an 8-inch projectile is two inches (with four cannelures), most of the simulations made so far were with .500 inch long slugs, (Figure 6); .282 inch, x .500 inch, x .800 inch. Visual examination of the engraved slugs reveals the following:

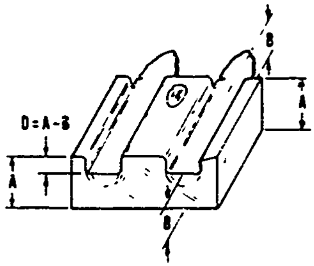
a. The backward push of engraved material by the simulated rifling land was exaggerated when compared with that of the actual retrieved rotating band.

b. The dull surfaces on the slug lands (Figure 7a) suggest, like the retention of machining marks on the retrieved rotating bands, that the simulator's rifling grooves were not completely filled with the engraved slug material. This is also supported by the groove depth "B" - height of the groove (Table I and in Figure 6), which reaches the full design depth of .070 inch only at the shiny spots. The total thickness of the engraved slug at its tail end, which is also where the grooves attain the full height of the engraver's land, is larger than its original (unengraved) thickness by .015 inch to .018 inch. This agrees with the observation that in an 8-inch tube despite prefiring interference of .044 inch to .055 inch, there is an incomplete filling of the rifling grooves. The mechanisms leading to this similarity are not necessarily the same, i.e., there is no radial pressure due to propellant gases in the simulator; although elastic strain might be imposed on the simulator's engraving plate bolts due to the normal component of the engraving force which is similar to the radial component in the actual gun tube during firing.

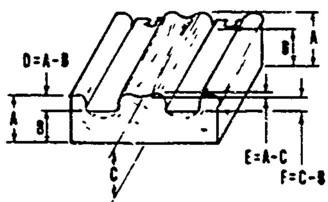


A = .282" FOR SIMULATING CONVENTIONAL C.o.R.
A = .252" FOR SIMULATING MODIFIED VERSION OF C.o.R

6a. SIMULATING SLUG BLANK



6b. ENGRAVED SLUG SIMULATING CONVENTIONAL C.o.R.



6c. ENGRAVED SLUG SIMULATING MODIFIED C.o.R.

Figure 6.

TABLE IA. DIMENSIONS OF SIMULATED ENGRAVING

<table>
<tr><th rowspan="2">Sample Number</th><th rowspan="2">Original Thickness
1. Bare
2. (With Shims)</th><th colspan="2">"A"
Total Height</th><th colspan="2">"B"
Height at the Groove</th><th colspan="2">"C"
Height at Channel in Lane</th></tr>
<tr><th>Front</th><th>Back</th><th>Front</th><th>Back</th><th>Front</th><th>Back</th></tr>
<tr><td></td><td>.282</td><td>.282</td><td>.309</td><td>.2335</td><td>.2405</td><td></td><td></td></tr>
<tr><td></td><td>.282</td><td>.3017</td><td>.3049</td><td>.2353</td><td>.2358</td><td>.2953</td><td>.3022</td></tr>
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<tr><td>2</td><td>.282</td><td>.286</td><td>.300</td><td>.229</td><td>.231</td><td></td><td></td></tr>
<tr><td>3</td><td>.282</td><td>.2785</td><td>.2960</td><td>.2250</td><td>.2260</td><td></td><td></td></tr>
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<tr><td>8</td><td>.252</td><td colspan="2">.280</td><td colspan="2">.218</td><td colspan="2">.255</td></tr>
<tr><td>9</td><td>.252</td><td colspan="2">.282</td><td colspan="2">.218</td><td colspan="2">.256</td></tr>
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<tr><td>14</td><td>.252</td><td colspan="2">.278</td><td colspan="2">.2092</td><td colspan="2">.2585</td></tr>
<tr><td></td><td>(.260)</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
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<tr><td>20</td><td>.252</td><td colspan="2">.266</td><td colspan="2">.2177</td><td colspan="2">.2605</td></tr>
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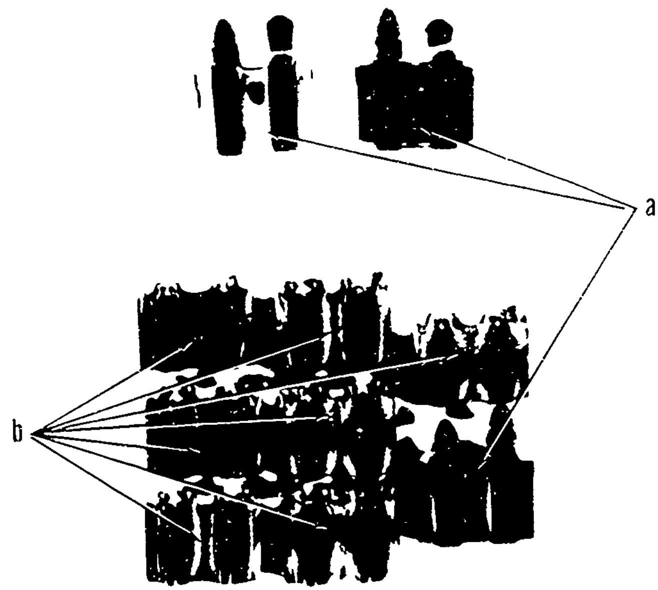
</table>

TABLE 1B. DIMENSIONS OF SIMULATED ENGRAVING

Sample Number	Original Thickness 1. Bare 2. (With Shims)	"D" = A-B Front	"D" = A-B Back	"E" = A-C Front	"E" = A-C Back	"F" = C-B Front	"F" = C-B Back	Material	Simulators Design	Remarks
	.282	.0485	.0685					Copper	Conventional	2.000" long
	.282	.0668	.0687	.0064	.0027	.0600	.0664	Copper	2nd Modification	2.000" long
1	.282	.0600	.0700					Copper	Conventional	
2	.282	.0570	.0690					Copper	Conventional	
3	.282	.0535	.0700					Copper	Conventional	
4	.282	.0555	.0700					Copper	Conventional	
8	.252	.062		.025		.037		Copper	1st Modification	Incomplete
9	.252	.064		.026		.038		Copper	1st Modification	
10	.252	.0655		.0285		.037		Copper	1st Modification	
12	.252	.065		.0230		.042		Copper	1st Modification	
13	.252	.0675		.0210		.0465		Copper	1st Modification	
	(.257)									
14	.252	.0688		.0195		.0492		Copper	1st Modification	
	(.260)									
15	.252	.066		.0190		.047		Copper	1st Modification	Incomplete
	(.260)									
19	.252	.042		.0050		.037		Gilding	2nd Modification	
20	.252	.0483		.0055		.0428		Gilding	2nd Modification	
	(.257)									
21	.253	.0526		.0052		.0474		Gilding	2nd Modification	
	.266									
22	.2535	.0586		.0056		.0530		Gilding	2nd Modification	
	(.2735)									
23	.2800	.0523		.0010		.0513		Gilding	2nd Modification	
24	.2800	.0617		.0102		.0515		Copper	2nd Modification	
26	.282	.0684	.0655	.0073	.0060	.0611	.0595	Copper	2nd Modification	2nd Slug in tandum of two



a – Simulation of the prevailing design of C o R

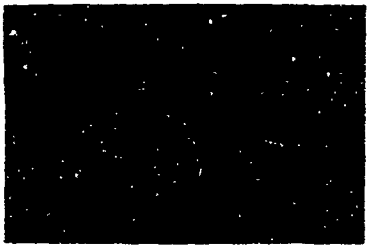
b – Simulation of the 1st modified design of C o R

ENGRAVED SIMULATING SLUGS

c. Micrographs reveal the following similarities between a rotating band engraved during firing and a laboratory slug engraved in the above simulator.

1. A cross section through the band/slug land material filling the groove spaces of the gun/simulator rifling is by and large undeformed (compare Figure 3c with Figures 8a and 9a). A narrow strip at the (band/slug) land's edge underwent deformation (compare Figure 3c with Figure 9b). The latter should be attributed to the shearing of the groove in the simulated slug and/or due to torsional wear in the rotating band of a fired projectile.

8a SIMULATING CONVENTIONAL C o R

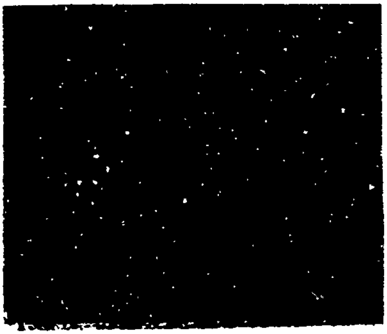


8b SIMULATING MODIFIED C o R

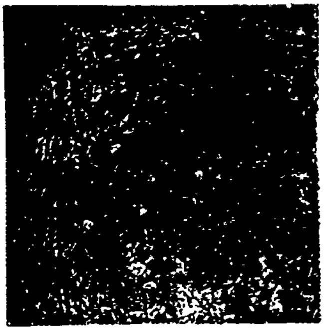
TRANSVERSE SECTIONS THROUGH ENGRAVED SLUGS

Figure 8.

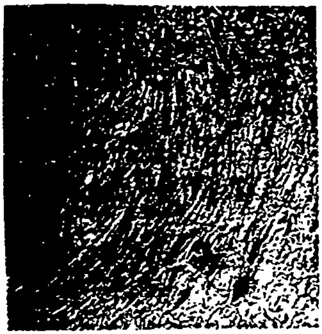
Reduced to 75 Percent of a 7X Magnification.



9a LAND SECT - SIMULATING CONV C o R



9b LAND SECT SIMULATING CONV C o R



9c GROOVE & LAND - SIMULATING MODIFIED C o R

9d LAND SECTION - SIMULATING MODIFIED C o R

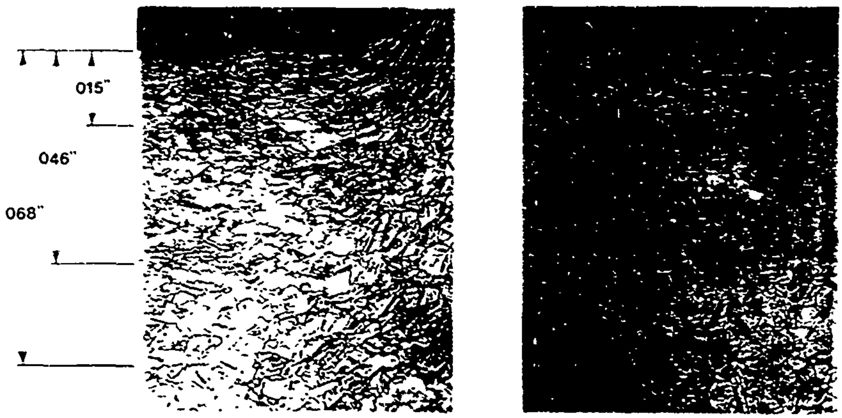
TRANSVERSE SECTIONS THROUGH ENGRAVED SLUGS

Figure 9.

Reduced from 50X Magnification.

2. In the engraved groove the following was observed: A layer of .008 inch below the surface of the fired band of the 105 mm projectile was heavily deformed and recrystallized (Figure 3b). In the simulated slug, a layer of up to .015 inch was heavily deformed without recrystallization (Figure 10a). Below the heavily deformed layer, one can detect deformation up to .055 inch to .075 inch below the surface of the fired rotating band and about .046 inch to .068 inch in the simulated slug.

On the other hand, comparing the engraved slugs simulating the present design of commencement-of-rifling with those of the modified design, led to the following observations:



10a SIMULATING CONVENTIONAL C o R

10b SIMULATING MODIFIED C o R

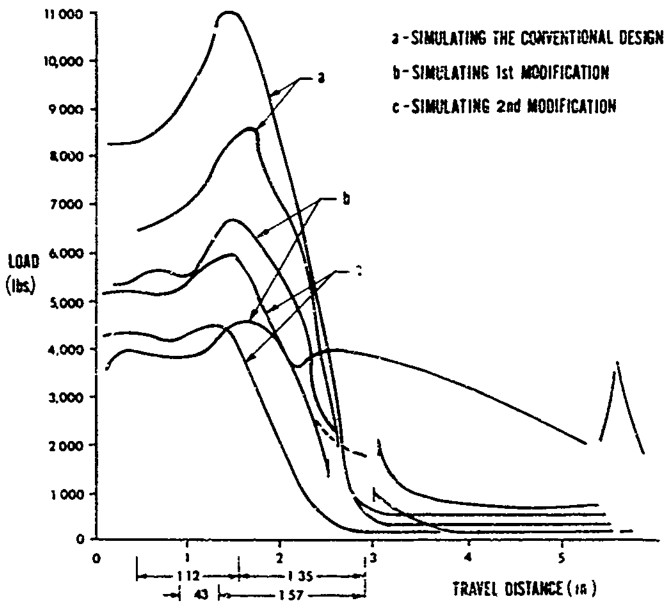
TRANSVERSE SECTIONS THROUGH ENGRAVED SLUG GROOVES

Figure 10.

a. In both cases swelling of the slug took place, although to a significantly lesser extent in the modified design. This is attributed to elastic tension in the bolts that hold the engraving plate onto the base block of the simulator. In both cases, this tensile strain in the bolts was believed to result from the vertical component of the engraving force acting on the engraving plate and transmitted to the bolts. And indeed, the engraving forces with the simulated modified design were significantly lower than those applied with the simulated conventional engraving (Figure 11).

b. In simulating the conventional design of commencement-of-rifling the groove material was pushed backward by the engraver's lands and the land section of the slug remained almost intact. (See Figures 9a and b.) This is evidenced by the narrow strips of deformed material at the groove edges, while the rest of the slug land remained unaffected by the deformation. In the slugs that were engraved through the modified design, however, a larger volume of material was deformed (a larger 'H' in Backhoffen's equation for redundant work, hence less redundant work). More significantly, the engraved land shows a buildup of material from the grooves being moved, which is the intent of the modified design. That indeed, this is the mode of deformation during engraving through the modified design, is evidenced from the following:

1. Very little material was pushed backwards (see Figure 7b), compared with slugs simulating conventional engraving (see Figure 7a).

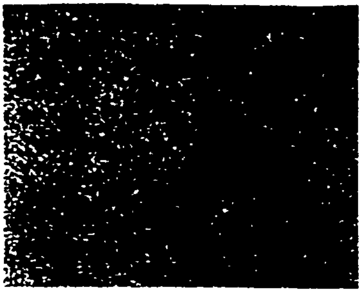


ENGRAVING FORCE VS. TRAVEL DISTANCE
(of the slug, through the engraving plate)

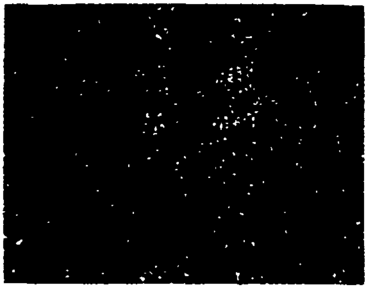
Figure 11.

2. The total height of the slug at its land is significantly larger than its undeformed thickness (see Figure 6 and Table I). At the same time, the slug's thickness at the grooves is comparable with the one to be anticipated from the engraver's land penetration of only .042 inch (out of a final anticipated land height of .070 inch). A correction for a slug swelling of .003 inch to .0188 inch should be considered.

3. The flow pattern, as evidenced through grain distortion in Figures 10, 12, and 13, confirms the above points 1 and 2; a thicker layer than the one observed in slugs simulating conventional engraving has been deformed under the groove. Moreover, it is clear from Figures 10b and 13b that this material flows towards the slug lands. The microstructures in Figures 13a and 13b clearly demonstrate this difference in deformation (metal-flow) patterns. Figures 9c and 9d confirm that indeed the grains in the slug land are deformed, and together with Figure 13b show that they are indeed part of a continual flow from the material under the slug grooves. Figures 9a and 9b, on the other hand, suggest that no such flow took place in the engraving that simulates the conventional commencement-of-rifling. Figure 9d also suggests, however, that there is less deformation at the center of the slug land than at the land edge. This will explain the failure to completely fill the grooves (Figure 8b).



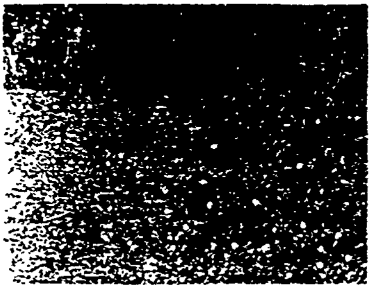
12a SIMULATING CONVENTIONAL C o R



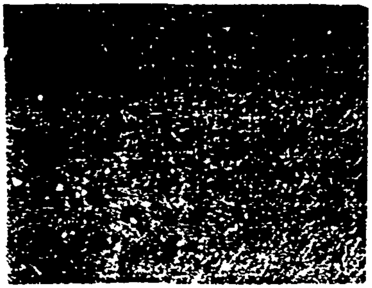
12b. SIMULATING MODIFIED C o R.

LONGITUDINAL SECTIONS THROUGH ENGRAVED SLUG GROOVES

Figure 12.



13a SIMULATING CONVENTIONAL C o R



13b SIMULATING MODIFIED C o R

TRANSVERSE SECTIONS THROUGH ENGRAVED SLUG GROOVES

Figure 13.

The failure to completely fill the engraver's grooves with the modified design led to a second modification in the design of the commencement-of-rifling. The improvement in deformation flow pattern with the latest modification and the effects of other possible factors, are presently being studied.

Figure 11 represents characteristic plots of engraving force vs. slug displacement (through the engraving plate). These graphs suggest a significant reduction in engraving force with the modified design, compared with the conventional design. A slight improvement over that of the first modification is also suggested for the second modification. However, other factors, not yet identified, might contribute to these differences. On the other hand, one should bear in mind that for reasons of expediency and economics, the engraving plates made in accordance with both of the modified designs are rough in the direction of the anticipated metal-flow, while the engraving plate that simulates the conventional design has a high degree of smoothness, particularly in the flow direction. Thus, in a smoother engraver, further lowering of engraving forces is to be anticipated for engraving with the modified design. In addition, in order to compensate for the unknown swelling of the engraving space due to transverse elastic strain in the bolts that hold the engraving plate, the undeformed slugs have been thickened. This leads to a high pre-engraving friction or even shaving, which distorts the pre-engraving share of energy consumption. Once the amount of prefiring interference is determined (in actual gun tube), these forces will be replaced by those required for a slight extrusion through the forcing cone (or be eliminated altogether.)

CONCLUSIONS

This study was based on the assumptions that:

a. Conventional commencement-of-rifling forces the displaced metal backwards during engraving.

b. Associated with such a mode of deformation, there is a lot of redundant work involved and as a result, higher forces are required during engraving. This means that a larger amount of energy is being consumed by the process. This excess energy can be better used for propelling the projectile.

c. The mode of deformation associated with larger redundant work and larger engraving forces will also result in higher wear.

This study was aimed at testing these assumptions, and set to modify the design of commencement-of-rifling in a way that will replace the above mode of deformation with one where metal-flow will be transverse to the slug/rotating band motion. Moreover, with the transverse metal-flow, larger volumes of material will participate in the deformation, being displaced shorter distances and with less redundant work and an overall lower engraving force and less energy consumption.

Assumptions a and b have been verified and two successive modifications of the design of the commencement-of-rifling were tested. These modified designs resulted in a transverse metal-flow at a reduced engraving force as they were set up to do. Factors affecting the total engraving force other than the mode of deformation have not been fully identified yet, and their effect has not been separated from the total force requirement. Also, the

transverse metal-flow obtained so far has failed to fully fill up the engraver's grooves as desired. Further studies are planned to identify and separate these other factors and to improve the transverse flow of the material.

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